Excitation of the second balance resonance by a radial rub

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This case history documents a rub during a recent startup of a steam turbine driven centrifugal compressor train. A major overhaul had been completed on the machine, and Bently Nevada was commissioned to document the startup.

During startup, overall vibration levels at bearing #4 increased significantly at approximately 9,800 rpm. The overall unfiltered vibration level was 2.0 mils (51 μm) peak-to-peak (Figure 2). Plant personnel were concerned that the vibration levels would continue to increase as the machine was brought up to its normal operating speed of 12,000 rpm.

The majority of the vibration occurred at 2X operating speed. The 2X amplitude fluctuated between 0.40 and 1.5 mils (10 μm and 38 μm) peak-to-peak. The 2X phase was fluctuating approximately 20°. The unsteady nature of this component provided a clue that a rub might be occurring. The first balance resonance of the compressor had been previously determined to be at approximately 6,500 cpm. Bently Nevada personnel speculated that a slight rub was occurring which was exciting the second balance resonance. At this point, there was no way to know what the second balance resonance was as it occurs above the operating speed of the machine.

Often, rubs will not clear themselves as the speed increases. Therefore, the speed of the machine was not directly increased. The speed was lowered to minimum governor and then increased to 12,000 rpm. There was no further evidence of the rub during this speed increase. The rub probably occurred at a newly-installed seal.

Further analysis indicated that this theory was correct. Often, if there is significant nX activity, where n is a multiple of the machine speed, the transient data can be filtered at nX to find any resonances which exist at these frequencies while the machine is operated at 1/n th of this speed. This neglects gyroscopic effects on the stiffness of the rotor which have an effect on the frequency of the observed balance resonance. Gyroscopic stiffening tends to stiffen the rotor for forward whirl modes. This raises the balance resonance and tends to soften the rotor for backward whirl modes, which lowers the balance resonance.

The vibration data had been recorded on tape. The taped shutdown data was sampled on the 108 Data Acquisition Instrument (108 DAI), with the 108's tracking filter set to track the 2X running speed component. The objective of reducing this data was to determine the approximate second balance resonance of the compressor rotor. The 2X amplitude and phase were tracked through the frequency range of interest (18,000 cpm to 24,000 cpm). Figure 3 illustrates a balance resonance at 19,100 cpm (actually slightly lower than the actual balance resonance because of gyroscopic effects).

The observed rub illustrates a Normal/Tight Mathieu type rub. The effect of the rub is to increase the net time-averaged spring constant of the rotor system substantially during the portion of the cycle that the rub occurs. This increases the average spring constant of the rotor system to a higher value. This tends to raise the rotor resonant speed by the factor:

$$\sqrt{\frac{K_{average}}{K_{normal}}}$$

At 9,800 rpm, the 2X component at this speed would be 19,600 cpm. The observed rub effectively stiffened the system and moved the approximate second balance resonance from 19,100 cpm to coincide with the 2X component of 19,600 cpm.

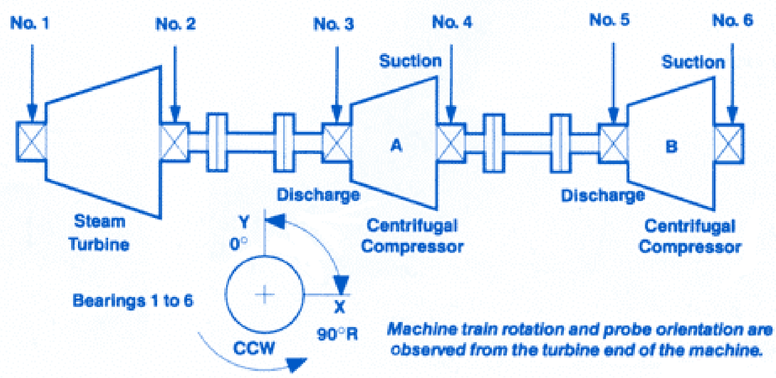

Figure 1
Machine train layout

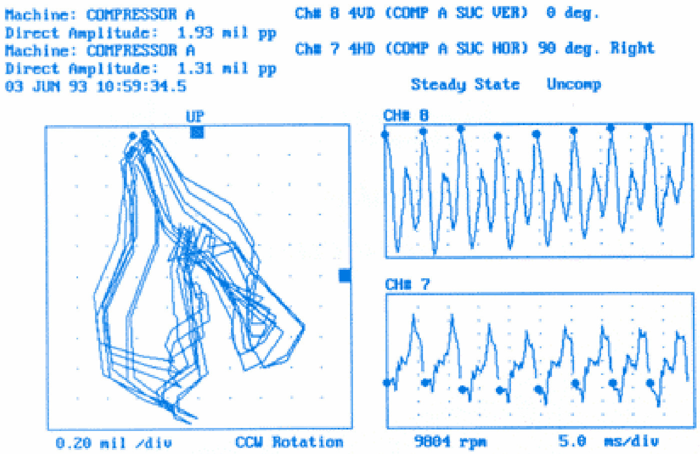

Figure 2
Orbit during rub

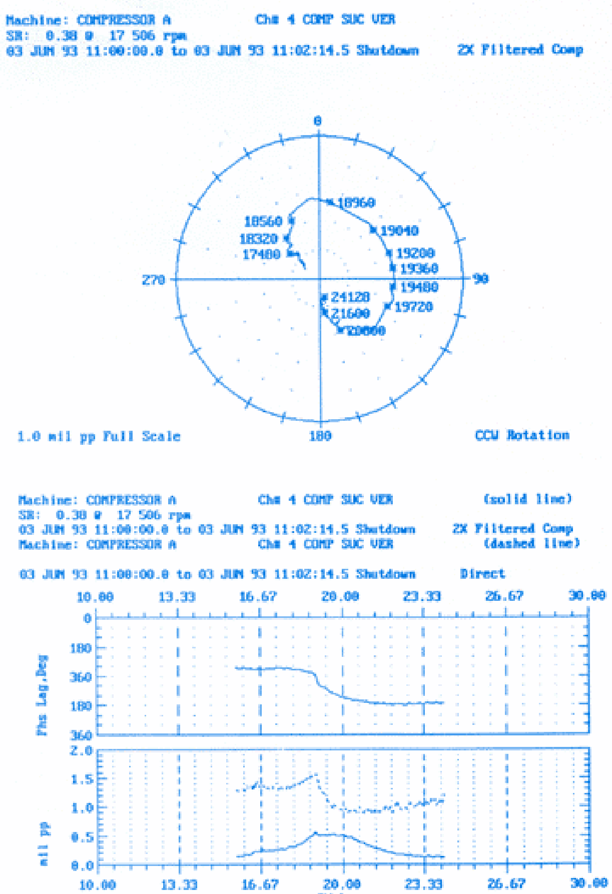

Figure 3
Coastdown filtered at 2X

Conclusion

This case history shows the effects of a fairly minor rub. It also illustrates the effective use of order tracking to approximate the frequency of a balance resonance above the operating speed of a machine. This case history also shows how this second balance resonance, or any resonance, can be excited by a rub. The use of the 108 DAI, with its 1X and 2X filter, was an important part of the diagnosis of this problem.

The 208 Data Acquisition Interface Unit (DAIU) and ADRE® for Windows, which are now available, will allow tracking of 1X, 2X and nX orders. This will allow you to track and study even higher order components, such as blade pass frequencies. ■

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By entering this contest, you are granting Bently Nevada Corporation the right to publish the article in the Orbit. All case histories must be authorized for publication by your Plant Management. Entries must be received by July 1, 1994. Send them to Mary Sue Matthews, Bently Nevada Corporation, P.O. Box 157, Minden, Nevada 89423 Fax: (702) 782-9337 or call (702) 782-3611 ext. 9493. ■